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ORIGINAL PAPER

A comparison of *Guibourtia copallifera* Benn. stands in South West Burkina Faso-community structure and regeneration

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Abstract: Shifting agriculture, fire, and over exploitation of wood and copal resin are the major causes of *Guibourtia copallifera* Benn. vulnerability in the south-west of Burkina Faso. Conservation of endangered species requires a thorough understanding of the dynamics of small populations. In the present study, we investigated the diversity and the dynamics of *G. copallifera* communities in two different types of land use history, a protected area (stated forest of Comoé-Leraba) and an unprotected area (the woodlands of Tourni and Timba). A total of 17 rectangular plots (50 m × 20 m) were sampled in both protected and unprotected areas. All woody species were systematically identified, measured and classified into diameter and height classes. In the two different types of land use, the dynamics of *G. copallifera*'s communities were good, and the diversities were similar and low with high β diversity.

Keywords: biodiversity conservation; shifting agriculture; vulnerable species; West Africa

Introduction

Tropical ecosystems are the most species-rich terrestrial communities in the world (Gaston 2000, 2007; Osborne 2000). It is estimated that in tropical forests there are about two-thirds of the estimated 250 000 plant species in the world (Myers 1980a, 1980b, 2003). However, they are the most threatened tropical terrestrial ecosystems due to the conversion of these areas into agricultural land (Khurana and Singh 2001). Growth in the human population is leading to depletion of food stocks; however, the efforts to enhance food production often result in significant environment degradation (Begon et al. 2006). Agriculture expansion and intensive resource extraction activities are also converting natural habitats into simpler, human-dominated landscapes. Significant areas of natural habitats were replaced by human-dominated systems, and the process of habitat destruction is probably the major cause of biodiversity loss. If the inhospitable land (rock, ice and deserts) is excluded, the proportion of human-impacted land will rise to 75%. Tropical forests are being cleared at the rate of 1%–2% per year with 40% of their original extent already lost (Myers 1992). Destruction of these forests reduces total habitat area and leads to habitat fragmentation, and the creation of isolated can not afford to support the variety of species in the patches.

There is rich plant diversity with over 1 693 vascular plant species identified in Burkina Faso (Schmidt 2006; Schmidt et al. 2005). Understanding the effects of diversity on ecosystem functioning and emergent community properties has become one of ecology's backbones. Direct,indirect, positive and negative effects of species on each other have the potential to be important mechanism driving the relationship between community diversity and ecosystem productivity, stability, invasibility, and resource cycling (Callaway 2007; Schemske et al. 2009). One of the central controversies in the literatures is whether diversity per se as well as the effects of particular species can enhance the ecosystem function (Spehn et al. 2002). Despite the considerable research effort was made on the plant species diversity in Burkina Faso at national scale (Fontes and Guinko 1995; Guinko 1984; Thiombiano 1996 and 2005), in protected areas (Guinko 2005; Mbayngone 2008; Mbayngone et al. 2008; Müller 2003; Ouédraogo 2006; Ouédraogo 2009; Ouédraogo et al. 2008; Ouoba 2006; Schmidt et al. 2008), in riparian corridors (Sambare et al. 2010), in specific plant communities (Bognounou et al. 2009; Thiombiano 1996 and 2005; Thiombiano et al. 2006), along the environmental gradients (Bognounou et al. 2009;

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Ouédraogo 2006; Thiombiano 1996), the comparison between specific communities at different successional stages did not receive a great deal of attention in the diversity-function literature.

G. copallifera Benn. communities are considered as a remnant of the primitive vegetation, and they are described as the theory proof of vegetation history. In the history poor land management was blamed for a steady and continuous destruction of vegetation from its presumed original forest climax (Aubréville 1939, 1949a and 1949b). They are rich in azonal species characteristic of more humid regions; however, they are extremely vulnerable to disturbances such as by fire and small-scale timber harvesting (Jaeger 1956), but human activities are secondary importance to edaphic factors in determining their distribution (Duvall 2003). In Burkina Faso, shifting agriculture, fire, and over exploitation of the wood and the copal resin seem to be the major causes of *G. copallifera* vulnerability. In fact, the species has high socio-economical values. The resin is used in pearl and pharmaceutical pill manufacturing, in carpentry varnishing, and in magic and religious rituals. The seeds, the stems and the leaves are used in traditional medicine. The wood is exploited in local house building. The studies were undertaken on the distribution and the use of the species (Arbonnier 2002; Aubréville 1949a; Bouquet and Debray 1974; Duvall 2003; Guy 1954), but the studies on its community dynamics are scarce or non-existent.

The objectives of this study were: (1) to assess the diversity of *G. copallifera* communities in two different types of land use history; (2) to estimate the dynamic of the communities through the patterns in diameters size classe's distribution. We hypothesized that the communities in the protected area should have the best dynamic and a higher species richness compared to those in the unprotected area, because nutrient availability (Crawley et al. 2005; Suding et al. 2005), defoliation (Collins et al. 1998; Olff and Ritchie 1998; Pietikainen et al. 2005) and disturbance (Collins et al. 1995; Connell 1978; Grime 1973) are the important factors influencing local species richness in plant communities. The effects of productivity and disturbance on species richness are likely to interact on the competitive outcome of multi-species dynamics (Huston 1994; Kondoh 2001; Stevens and Carson 2001). Local species richness is also influenced by the balance between colonization and extinction rates (Gibson and Brown 1991; Olff and Ritchie 1998; Stevens 2006).

Materials and methods

Study area

The study was undertaken in the protected area of Comoé-Léraba and the unprotected woodlands of Tourni and Timba located in the South-western part of Burkina Faso between the latitudes 9°25′N and 11°5′N, and the longitudes 5°35′W and 3°30′W (Fig. 1). The protected area was established from two existing classified forests (Diéfoula and Logoniégué) respectively classified in 1937 and 1955. Two forests were poorly managed leading them to degradation due to anthropogenic disturbances (agriculture, wood logging and late fire). So, the two classified forests were conceded to a local association FREM «Comoe-Leraba classified Forest and Fauna partial Reserve's inter-villages Association of natural resources Management» for integrated management based on local population participation. The South West of Burkina Faso is characterized by a tropical climate of the Sudano-guinean type, with two alternating seasons: a short dry season from December to February, and a long rainy season from March to November with mean annual rainfall of 1 000 mm. The number of rainy days per year exceeds 90 days. The maximum temperature is 36°C in March-April and the minimum temperature is 16°C in December. Phyto-geographically, the study sites are located in the Comoé district of the South Sudanian sector (Fontes and Guinko 1995; Guinko 1984). It includes the densest forest formations with some patches of dense non-riparian forests (Duvall 2003; Neumann and Müller-Haude 1999). The vegetation is characterized by Sudanian species associated with Guinean riparian species such as *Cola laurifolia* Mast, *Manilkara multinervis* (Bak.) Dubard, *Elaeis guineensis* Jacq., *Dialium guineense* Willd. and *Antiaris africana* A. Chev. The common species are *Acacia sieberiana* DC., *Anogeissus leiocarpa* (DC.)Guill.&Perr., *Burkea africana* Hook., *Daniellia oliveri* (Rolfe) Hutch. and Dalziel, *Diospyros mespiliformis* Hochst. ex A. DC., *Isoberlinia doka* Craib and Stapf, and *G. copallifera*. The most frequently encountered soils are cambisol and lithic leptosol according to the FAO soil classification system (Driessen et al. 2001).

Study species

G. copallifera Benn. is a species of Caesalpinoideae subfamily and Fabaceae family. It is a tree or a shr of 15−25 m high, bole swollen at base with short sharp buttresses extending upwards as fluting to 12 m height. *G. copallifera* Benn. is found in the Sudano-Zambezian and Sudano-Guinean zones of Africa. In West Africa, it is present in Senegal, Sierra Leone, Guinea, Mali, Côte d'Ivoire, Nigeria, Benin, Burkina Faso, and extends into Congo and Democratic Republic of Congo in Central Africa (Bouquet and Debray 1974). It colonizes dry forests, Sudanian and Guinean riparian forests, rocky hills and the banks of streams (Arbonnier 2002). In Burkina Faso, it is found in the southern part of the country where the species is rarely found in the isolated individuals. The few patches of dense non-riparian forests constituted by the species are evergreen and colonize the floodplains of the Comoé and Léraba rivers, and also woody savannas, sandstone cliffs (Anonymous 2005).

Data collection

The plant survey was conducted in two different types of land use history through *G. copallifera* communities using an unbalanced, a completely randomized design: a protected area (stated forest of Comoé-Leraba) and an unprotected area (the woodlands of Tourni and Timba). The plots were rectangular with the sides of 50 × 20 m. A total of 17 quadrats (11 in the protected area and 6 in the unprotected area) were laid out in representative areas

for collecting data. The unbalance of the survey is due to the scarcity of the *G. copallifera* communities in the non protected areas. Each sample plot was systematically surveyed, and all woody species were recorded and identified. The species were determined on the field using Arbonnier (2002) field book, and in the lab using different floras (Hutchinson and Dalziel 1954, 1958, 1963, 1968, 1972; Hawthorne and Jongkind 2006). The following variables were also recorded: the number of individuals per species and the diameter at 1.30 m of individuals with DBH ≥ 5 cm. The number of the stems of the multi-stem individuals was counted and the quadratic diameter was calculated for the data analysis (Glele Kakai et al. 2005). The individuals with DBH < 5 cm were considered as juveniles. The juveniles' survey was carried out within two subplots per quadrat with the size 5 × 5 m of each plot. Within each subplot, the number of juveniles and the total height of each juvenile were recorded.

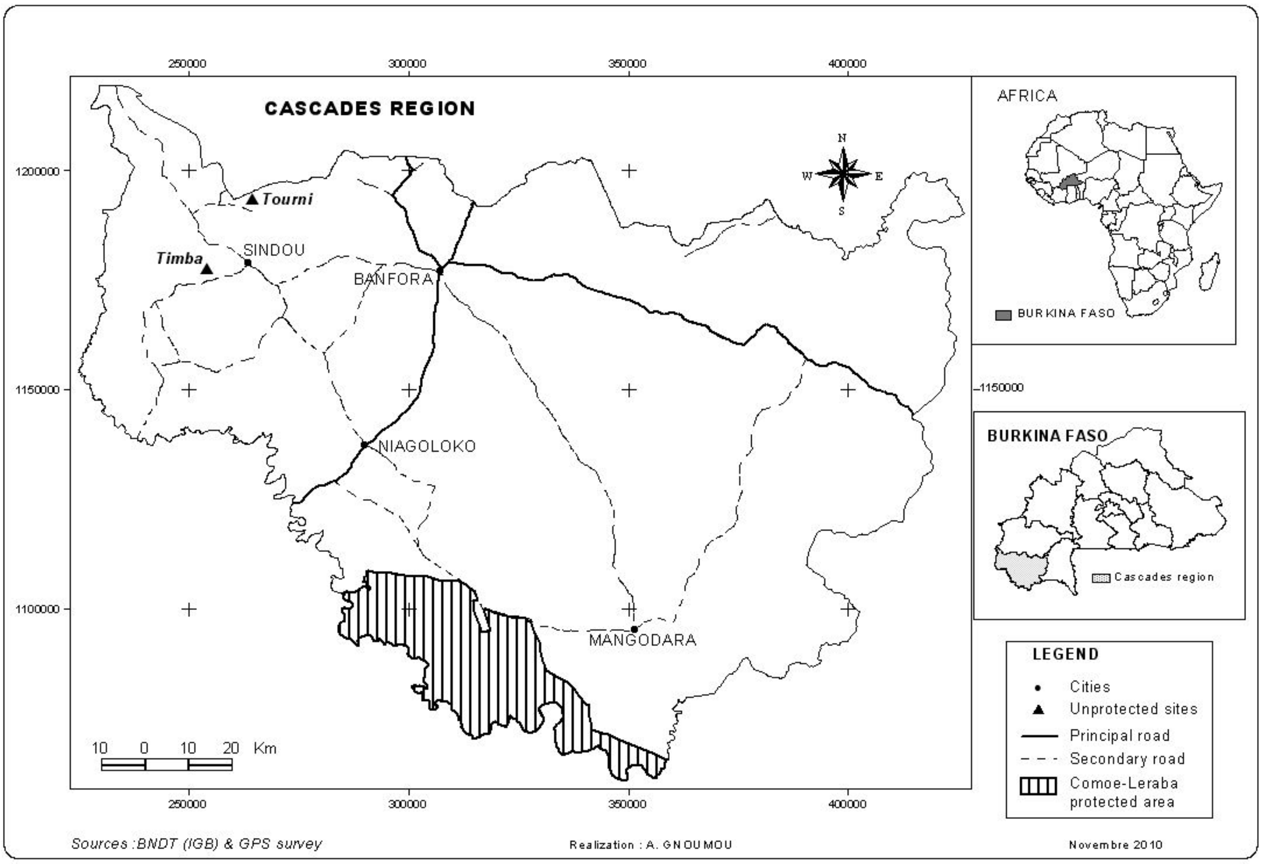

Fig. 1 Study zone with the location of the study sites

Data analysis

Species richness alone is often insufficient to compare the diversity of two different communities, because it does not take into account the relative abundance of each species (Krebs 1999). To fill this gap, Shannon diversity index (H') which considers both richness and relative abundance of species (Magurran 2004) was calculated. H' is used to quantify the heterogeneity of the species diversity of an environment. Pielou's Evenness index (J) was also calculated to compare the evenness of species distribution. When the evenness is perfect $\ln S = H'$, so, $J = 1$ (McCune and Grace 2002). These different indices were calculated from the following equations:

Shannon diversity index: $$H' = -\sum_{i=1}^{s} p_i \ln p_i \quad (1)$$

Pielous index: $$J = H' / \ln S \quad (2)$$

where, S is the total number of species in the community (richness) and p_i is the proportion of individuals belonging to the species i. The value of H' is minimal ($H' = 0$), when all individuals of the community belong to a single species. The index is maximal when all species have the same number of individuals within the community (Magurran 2004). The easiest way to measure the similarity between sites is by using similarity coefficients. The Jaccard and Sørensen's similarity indices were calculated to measure the β diversity of pair of sites (protected and unprotected). They were calculated based on presence/absence data of the species. Both indices potentially vary between 0 and 1, and the value close to 1 indicates greater similarity between sites, hence, low β diversity (Magurran 2004). They were calculated from the following equations:

Jaccard Index: $C_j = \dfrac{j}{a+b-j}$ (3)

Sørensen index: $C_s = \dfrac{2j}{2j+a+b}$ (4)

where, j is the number of species held in common, a is the number of species found at only the site A, and b is the number of species found at only the site B. The relative ecological importance of each woody species in the plots at each site was expressed using the Importance Value Index (IVI) (Heikkinen and Birks 1996). This index was calculated from the following equations:

$$\text{DBH area} = \mathrm{D}_{1.30}^2 \frac{\pi}{4} \tag{5}$$

where, $\mathrm{D}_{1.30}$ is the DBH.

$$\text{Relative Dominance} = \frac{\text{Total basal area of a species}}{\text{Total basal area of all species}} \times 100 \tag{6}$$

$$\text{Relative Density} = \frac{\text{Number of individuals of a species}}{\text{Total number of individuals}} \times 100 \tag{7}$$

$$\text{Frequency} = \frac{\text{Number of plots in which the species occurs}}{\text{Total number of plots}} \times 100 \tag{8}$$

$$\text{Relative Frequency} = \frac{\text{Frequency of a species}}{\text{Sum of all frequencies}} \times 100 \tag{9}$$

$$\text{IVI} = \text{Relative Dominance} + \text{Relative Density} + \text{Relative Frequency} \tag{10}$$

where, IVI is the importance value index.

The value of relative dominance, relative frequency, relative density and relative diversity fluctuates between 0 to 100%, so that IVI of species may vary between 0 and 300%. Structural characteristics (density, plant's habit, diameter and height class distributions) were computed for each plot and averaged per site for all individuals. The plants were grouped into 21 diameter classes of 5 cm interval (5 cm ≤ diameter ≤ 110 cm). The juvenile individuals were grouped into 7 height classes with 0.5 m interval (0 ≤ height ≤ 4 m). Several methods were used to describe the stand structure of trees. Weibull distribution was used in this study, because it is a widely used model in the description of some forests (Ryniker et al. 2006) and seems to be the best suited (Merganic and Sterba 2006). So, Weibull function was used to model the stand structure (diameter classes) of the plant communities on the basis of the following equation:

$$f(x,\alpha,\beta) = \alpha\beta^{-\alpha}x^{\alpha-1}e^{\left[-(\frac{x}{\beta})^{\alpha}\right]} \tag{11}$$

where, β is the shape parameter also known as Weibull slope, α is the scale parameter which scales x variable probability distribution, and x is the variable (diameter). When $\beta < 2.6$, the plant community is ideally stable. When $2.6 < \beta < 3.7$, the plant community is instable. When $\beta > 3.7$, the plant community is aging. A change in the scale parameter α has the same effect on the distribution as a change of the abscissa scale. The skewness parameter (g) was also calculated. When $g < 0$, the plant community is aging. When $g > 0$, the plant community is stable. And when $g = 0$, the plant community is degraded.

Initial exploration of the data indicated the violation of normality assumption among the response variables. So, we used the Wilcoxon test to compare the medians of species richness, diversity indices, individual density and basal area. Wilcoxon test is a non-parametric alternative to Student's t test, which could be used if the error distribution looks non-normal. The non-parametric test is more appropriate than the t test when the errors are not normal, and the non-parametric is about 95% as powerful with normal errors, and can be more powerful than t test if the distribution is strongly skewed by the presence of outliers (Crawley 2005). The multi-stemmed and single-stemmed individuals' proportion was analyzed with generalized linear models by using penalized quasi-likelihood with binomial errors. Generalized linear models with binomial errors were used to account for the non-normal errors and the inconstancy in variances that are associated with proportional data. Penalized quasi-likelihood estimation was used in order to account for overdispersion and underdispersion (Crawley 2005). The car package was used to perform the ANOVA using the type III sum of squares for a non-orthogonal design. All statistical analyses were performed in the R statistical package (R development Core Team 2010). The Excel and JMP 7 software were used for graphs drawing.

Results

G. copallifera community's diversity and similarity

Species richness was significantly similar in the two types of land use (w = 42, N = 17, p = 0.38). The mean species richness was 4.45±0.59 (mean ± SE) species in the unprotected area and 5.17±0.54 species in the protected area. A total of 38 species representing 30 genera and 19 families were found in the two areas, of which 23 and 16 species were encountered in the protected and the unprotected area respectively (Table 1 and 2). In regard to chorological affinities, 65.22% of protected area species were Guineo-congolese species against 6.25% in the unprotected area. *G. copallifera* communities' diversity was low in both areas and significantly similar according to Shannon diversity index (w = 45, N = 17, p = 0.26). The mean value of Shannon index was 0.30 ± 0.03 in the protected area and 0.25±0.04 in the unprotected area. The evenness was also low and significantly similar in both areas according to Pielou evenness index (w = 35, N = 17, p = 0.88). Pielou index were 0.43±0.03 and 0.41±0.05 in the protected and the unprotected area respectively. The similarity between the two areas was low according to Jaccard index (C_j = 0.025) and Sørensen index (C_s= 0.046). The two types of area had only *G. copallifera* as a common species, and it was the most important species with IVI = 198.68 in the protected area (Table 2) and IVI = 187.83 in the unprotected area

(Table 3).

Table 1. Chorological affinities, families, and importance value index of *G. copallifera* communities' species in the protected area

Species	Chorological affinities	Family	Density (N/ha)	Relative Frequency (%)	Relative Density (%)	Relative Dominance (%)	IVI
Guibourtia copallifera Benn.	Guineo-Congolese	Fabaceae	9250	22.45	83.94	92.29	198.68
Diospyros heudelotii Hiern	Guineo-Congolese	Ebenaceae	690	16.32	6.26	1.14	23.73
Diospyros mespiliformis Hochst. ex A. DC.	Paleotropical	Ebenaceae	150	14.29	1.36	3.59	19.23
Pterocarpus santalinoides DC.	Guineo-Congolese	Fabaceae	340	4.08	3.09	1.22	8.39
Diospyros abyssinica (Hiern) F. White	Guineo-Congolese	Ebenaceae	180	4.08	1.63	0.18	5.89
Drypetes floribunda (Müll. Arg.) Hutch.	Guineo-Congolese	Euphorbiaceae	150	4.08	1.36	0.28	5.72
Cryptolepis sanguinolenta (Lindl.) Schltr.	Guineo-Congolese	Apocynaceae	40	4.08	0.36	0.06	4.5
Tamarindus indica L.	Paleotropical	Fabaceae	10	2.04	0.09	0.51	2.64
Alafia scandens (Thonning) De Wild.	Guineo-Congolese	Apocynaceae	20	2.04	0.18	0.29	2.52
Strychnos usambarensis Gilg	African Multiregional	Loganiaceae	30	2.04	0.27	0.02	2.34
Mallotus oppositifolia (Geiseler) Müll. Arg.	African Multiregional	Euphorbiaceae	30	2.04	0.27	0.02	2.33
Dialium guineense Willd.	Guineo-Congolese	Fabaceae	20	2.04	0.18	0.05	2.27
Napoleonaea vogelii Hook. & Planch.	Guineo-Congolese	Lecythidaceae	10	2.04	0.09	0.14	2.27
Combretum tarquense J.J. Clark	Guineo-Congolese	Combretaceae	20	2.04	0.18	0.04	2.26
Cassia sieberiana DC.	Sudano-Zambesian	Fabaceae	10	2.04	0.09	0.08	2.21
Anogeissus leiocarpa Guill. & Perr.	Sudano-Zambesian	Combretaceae	10	2.04	0.09	0.02	2.15
Cassipourea congoensis R. Br. Ex DC.	Guineo-Congolese	Rhizophoraceae	10	2.04	0.09	0.02	2.15
Dalbergia hostilis Benth.	Guineo-Congolese	Fabaceae	10	2.04	0.09	0.02	2.15
Crataeva adansonii DC.	Paleotropical	Capparaceae	10	2.04	0.09	0.01	2.15
Uvaria chamae P. Beauv.	African Multiregional	Annonaceae	10	2.04	0.09	0.01	2.14
Dennettia tripetala Bak. f.	Guineo-Congolese	Annonaceae	10	2.04	0.09	0.01	2.14
Landolphia hirsuta (Hua) Pichon	Guineo-Congolese	Apocynaceae	10	2.04	0.09	0.01	2.14

Table 2. Chorological affinities, families and importance value index of *G. copallifera* communities' species in the unprotected area

Species	Chorological affinities	Family	Density (N/ha)	Relative Frequency (%)	Relative Density (%)	Relative Dominance (%)	IVI
Guibourtia copallifera Benn.	Guineo-Congolese	Fabaceae	2160	19.35	82.13	86.34	187.83
Lannea acida A. Rich.	Sudanian	Anacardiaceae	90	16.13	3.42	2.66	22.21
Bombax costatum Pellegr. & Vuill.	Sudanian	Malvaceae	50	9.68	1.9	2.08	13.66
Detarium microcarpum Guill. & Perr.	Sudanian	Fabaceae	60	9.68	2.28	0.44	12.4
Ficus thonningii Blume	Sudanian	Moraceae	60	6.45	2.28	0.68	9.41
Erythroxylum emarginatum Thonn.	African Multiregional	Erythroxylaceae	40	6.45	1.52	0.19	8.16
Mimusops kummel Bruce ex A. DC.	Sudanian	Sapotaceae	50	3.23	1.9	2.09	7.21
Breonadia salicina (Vahl) Hepper & Wood	Sudanian	Rubiaceae	10	3.23	0.38	2.32	5.93
Ficus platyphylla Del.	Sudanian	Moraceae	10	3.23	0.38	1.15	4.75
Pterocarpus erinaceus Poir.	Sudano-Zambesian	Fabaceae	10	3.23	0.38	0.9	4.51
Vitex doniana Sweet	Afro-Tropical	Verbenaceae	20	3.23	0.76	0.45	4.43
Lannea microcarpa Engl. & K. Krause	Sudano-Zambesian	Anacardiaceae	20	3.23	0.76	0.28	4.26
Hexalobus monopetalus Engl. & Diels	Sudano-Zambesian	Annonaceae	20	3.23	0.76	0.16	4.15
Lannea velutina A. Rich	Sudanian	Anacardiaceae	10	3.23	0.38	0.11	3.72
Opilia celtidifolia (Guill. & Perr.) Endl. Ex Walp.	Sudano-Zambesian	Opiliaceae	10	3.23	0.38	0.12	3.72
Combretum adenogonium Steud. ex A. Rich.	Sudanian	Combretaceae	10	3.23	0.38	0.04	3.64

Table 3 Summary of the stand structure parameters of *G. copallifera* communities in the both area

Parameters	Protected area		unprotected area	
	Population	Community	Population	Community
Skewness (g)	1.93	2.10	3.05	2.98
Weibull shape (β)	1.35	1.33	1.49	1.52
Weibull scale (α)	17.84	18.31	15.37	15.13

G. copallifera communities stand structure

The protected area's communities were significantly denser than the unprotected one (w = 0.5, N = 17, p = 0.001). The densities were 1001.82±55.45 Ind.·ha^{-1} and 438.33±48.81 Ind. ·ha^{-1} in the protected and unprotected areas respectively. The tree basal area in the protected area was significantly more important than in the unprotected one (w = 2, N = 17, p < 0.001) with 37.95±4.25 m^2·ha^{-1} against 9.90±2.71 m^2·ha^{-1}. The structure of the diameter size class distribution was similar in the two different types of area. The distributions displayed a reverse "J" shaped curve: a majority of plants were found in the first diameter size class and the density of individuals diminished as the size class increased (Fig. 2). The Weibull shape parameter β was lower than 3.6 with

a positive skewness (Table 3).

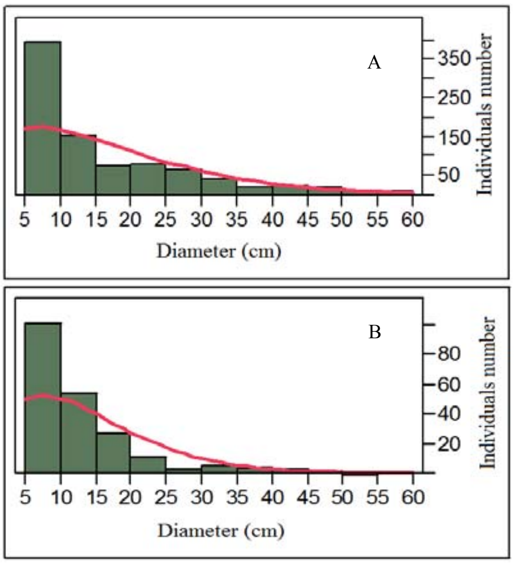

Fig. 2 Stand structure of *G. copallifera* communities with Weibull function in protected area (A) and in non-protected area (B).

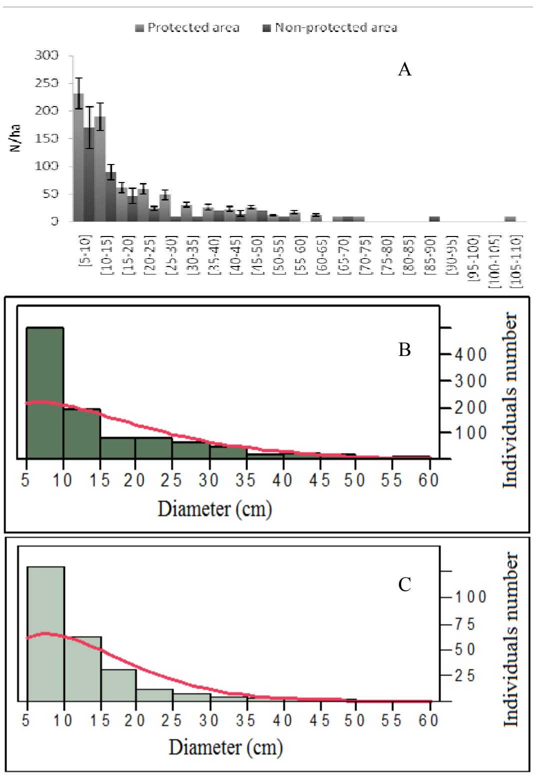

Fig. 3 Stand structure of *G. copallifera* population (A: comparative structure; B: Stand structure in protected area with Weibull function; C: Stand structure in non-protected area with Weibull function).

G. copallifera population stand structure

The individuals of *G. copallifera* were significantly denser in the protected area than the unprotected one (w = 1, N = 17, p = 0.001; 842.73±63.29 individuals.·ha^{-1} against 360.00±39.67 individuals.·ha^{-1}). Their basal area was significantly important in the protected area than that in the unprotected one (w = 1, N = 17, p < 0.001; 35.02±4.28 m^2·ha^{-1} against 8.55±2.62 m^2·ha^{-1}). The mono-stem individuals were significantly denser in the protected area than that in the unprotected one (w = 4, N = 17, p = 0.004; 721.10±67 individuals.·ha^{-1} against 181.67±26.51 individuals.·ha^{-1}). The multi-stem individuals' densities were significantly similar in the two areas (w = 46, N = 17, p = 0.21) with 121.82±24.11 individuals.·ha^{-1} in the protected area and 178.33±16.21 individuals.·ha^{-1}in the unprotected one. The proportion of multi-stem individuals was significantly larger in the unprotected area than that in the protected area ($F_{[1;15]}$ = 46.52, p < 0.001; 50.34±2.69% against 16.43±4.59%). The structure of the diameter size class distribution of *G. copallifera* tree's population was similar in the protected and the unprotected areas with a reverse "J" shaped curve (Fig. 3, Table 3, β < 3.6, g > 0). The juveniles' density was significantly similar in the two areas (w = 45, N = 17, p = 0.18) with 9.28±1.15 individuals.·m^{-2} in the protected area and 7.24±1.88 individuals.·ha^{-1} in the unprotected one. The juveniles' height class distributions displayed a reverse "J" shaped curve (Fig. 4).

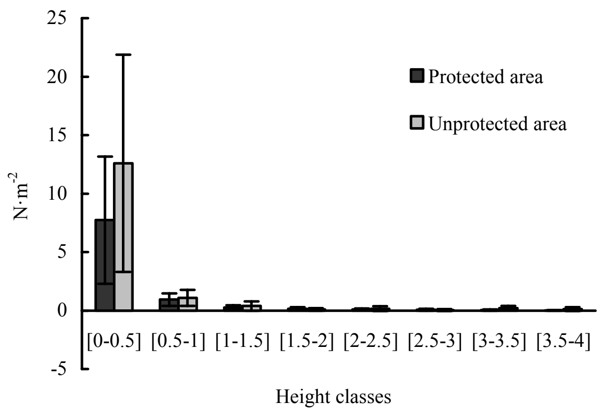

Fig. 4 Comparative stand structure *G. copallifera* juveniles in the two different types of land use history

Discussion

The number of overall species richness reported in this study accounts for about 30% of the protected woody species. Gnoumou et al. (unpublished data) reported 128 woody species representing 95 genera and 39 families in the protected forest of Comoé-Leraba. The results show significant similarity of *G. copallifera* communities in species richness on the two different types of land use, but there was more species in the protected area.

Many studies suggest that the species richness of vascular plants in general is strongly related to capturable energy such as temperature (solar radiation) and precipitation (Currie and Paquin 1987; Lieth 1975; Richerson and Lum 1980; Rosenzweig and Sandlin 1997; Wright 1983). There is more shade in the protected area than that in the unprotected one. The shade benefits to the understory plants by maintaining plant tissues below lethal or near-lethal temperatures, decreasing respiration cost, lowering transpirational demands by decreasing the vapour pressure difference between leaves and air, reduction of ultraviolet irradiation, increased soil moisture due to lower evaporation demand, and limiting light damage (Callaway 2007; Schemske et al. 2009). Diversity indices (Shannon and Pielou) showed low and similar diversity between the two areas and this could be attributed to the importance of *G. copallifera* in the communities. Indeed, the Importance Value Index (IVI) of *G. copallifera* was the highest in the communities. However, the similarity indices (Jaccard and Sørensen) in species compositions showed a low similarity between the two different types of land use. This low similarity could be explained by the delicate balance of environment factors such as soil, climate, topography, geography, fire, time, herbivory and human disturbances (Bellefontaine et al. 2000; Hillebrand 2004; Wiens and Donoghue 2004). Solar radiation, temperature, and precipitation, in particular, have been shown to correlate with plant diversity (Richerson and Lum 1980; Wright 1983). The best environmental correlate of plant diversity on the large scale is Actual evapotranspiration (Lieth 1975; Rosenzweig 1968). Actual evapotranspiration is the amount of water that actually evaporates or is transpired from an area. Actual evapotranspiration represents the joint availability of energy and water.

The results indicate that the density, basal area of the communities and the populations of *G. copallifera* were higher in the protected area than those in the unprotected area. In fact, the forest management favours the establishment and the growth of seedlings. On the other hand in the unprotected area, the surrounding populations exploit the plant resources without a management plan. The massive losses of saplings and trees are mainly imputable to agriculture and overexploitation (Duvall 2003). Shifting agriculture is a widespread form of land use and a major cause of deforestation (Osborne 2000). Shifting agriculture involves a cycle of forest clearing, litter burning, cropping and forest recovery.

The results show that *G. copallifera* multi-stemmed individuals were denser in the unprotected area than that in the protected area. This differential response of morphology could be explained by *G. copallifera*'s biology and ecology such as its coppicing ability (Bellefontaine 2005), as well as its resilience to varying environmental conditions such as fire, woodcutting and browsing. Apparently, the high sprouting capacity may be the consequence of a historically extensive disturbance regime (Fries and Heermans 1992). The high sprouting capacity is consistent with the view that sprouting is a persistence strategy of savanna-woodland species (Ky-Dembele et al. 2007) and disturbed sites (Nzunda et al. 2007). This is in agreement with several lines of evidence that indicate the importance of the sprouting ability of woody species in tropical woodlands (Bognounou et al. 2010; Kozlowski 2002; Ky-Dembele et al. 2007).

The juvenile population of *G. copallifera* is larger in the unprotected area than that in the protected area. Establishment, survival and growth of juveniles is governed by several biotic and abiotic factors (Fenner and Thompson 2005). The observed patterns in the juvenile populations could be mainly ascribed to seed aging, the medium of seed germination (soil flooding and compaction), failure of seed to germinate, competition for light and nutrient, predators, pathogens, and disturbances (Kozlowski 2002). The higher light transmittance in stands of the unprotected area could stimulate germination and growth of the species (Osborne 2000). Moreover, juveniles from sprouting have relatively high survivorship in relatively harsh environmental conditions in comparison with juveniles from sexual regeneration (Kiltajima and Fenner 2000) since they depend on the already established root system of the original trees for accessing water and nutrient. This might explain also the larger number of juveniles in the unprotected area where the most frequently encountered soils are arid (Duvall 2003).

The stand structures of the communities, the populations and the juveniles are similar in the two areas and indicate an excellent regeneration dynamic. Seedlings establishment is an important part of vegetation dynamics, as the recruitment of seedlings determines the composition of the future population (Vieira and Scariot 2006). According to Peters (1997), the ultimate criterion according to which the biological strategy of plant species must be estimated is its capacity to recruit new juveniles to maintain its population. In the reverse "J" shaped curve structure, the dead plants are compensated by the growth of the individuals from the low size classes. Many researchers consider this structure as the ideal stable plant population, because it maintains itself (Peters 1997; Zegeye et al. 2006). There are a large number of juveniles in the inferior classes, indicating a potential renewal of the population of *G. copallifera* (Peters 1997; Teketay 1996; Zegeye et al. 2006). The high density of juveniles and their stand structure show that the species have a good potential of regeneration in both areas. But, these juveniles may go through highly variable precipitation, frequent dry periods, grazing and fire, which are important drivers of mortality (Marod et al. 2002; Menaut et al. 1995; Swaine 1992; Vieira and Scariot 2006). This situation makes the juveniles' survival unpredictable because of complex interactions among soil, climatic conditions and regeneration mechanisms including seeds in seed banks and those dispersed into a site as well as sprouting.

On the whole, the *G. copallifera* communities and populations show good regeneration dynamics. So, why the species was quoted as a vulnerable species by some studies (IUCN 2004) and today is not listed in the current IUCN red list? A vulnerable species is one which has been categorized by IUCN as likely to become endangered unless the circumstances threatening its survival and reproduction improve. Vulnerability is mainly caused by habitat loss or destruction. Vulnerable species are monitored and are becoming threatened. On the basis of these definitions, both governments and non-governmental organizations have produced threaten species lists. These lists provide a

starting point for setting priorities for developing to manage individual species. The conservation of endangered species requires a thorough understanding of the dynamics of small populations. In fact, the populations of *G. copallifera* are rare in unprotected areas. Species that are at high risk of extinction are almost always rare (Begon et al. 2006). Nevertheless, rare species, just by virtue of their rarity, are not necessarily at risk of extinction, and Duvall (2003) shows that virtually all depictions in the botanical literature of *G. copallifera* have been essentially symbolic rather than scientific: the existence of this species has been used to represent the accuracy of anthropogenic disturbance theory, although the data this species represent have not been analyzed in a manner that allows rigorous testing of the theory. It is clear that many, probably most species are naturally rare. In our case, the existing populations are confined to waste land, and their exploitation is still increasing the threat. Moreover, landless peasants, wild fires, diseases, extreme weather phenomena and climatic processes take no notice of protected areas' boundaries; already a good share of tropical forest parks and reserves have undergone encroachment by subsistence farmers (Myers 2003). So, there is a need to do much more than establish parks and reserves, imperative though this.

Conclusion

The communities of *G. copallifera* have a similar and low diversity with high β diversity in protected and unprotected areas. Its populations' dynamic has a good trend, with a stand structure reflecting a reverse "J" shape. But this dynamic is governed by a high level of demographic, environmental and spatial uncertainties. Therefore, *G. copallifera* deserves special environmental attention because its extinction will lead to the extinction or large changes in abundance of several species. It provides resources on which many species depend.

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